“Compact TT&C Equipment for Small Satellites”

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Session 2: On-Board TTC Technologies
Co-chairs: I. Stojkovic & E. Daganzo, ESA/ESTEC, NL
Compact TT&C Equipment for Small Satellites

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INTRODUCTION
In recent years, the segment of small satellites has acquired bigger importance in the space business due to the increased number of missions. Earth Exploration has now commercial applications and this fact has developed the demand of LEO satellites. The limited budget and simplified requirements of these missions make small satellites well placed to serve this market.

Several factors have imposed new constraints over the TT&C systems. We can highlight some of the most important:

- The higher TC and TM data rates demanded by the operators
- The need of a better spectrum use with more efficient modulation schemes
- The availability of GPS and the existence of space qualified GPS receivers
- The reduced mass, volume and power budget that can be allocated to TT&C in a small satellite

This paper describes these new constraints and the implemented solutions in two small European multipurpose platforms: PROTEUS and LEOSTAR, whose first programs are going to be launched soon.

EVOLUTION AND NEW DEMANDS OF TT&C FOR SMALL PLATFORMS
The small platforms match the requirements of LEO observation missions. These missions have a reduced number of instruments and their demand in terms of mass and power is typically moderated. In addition, the requirements of a LEO satellite can be easily met with a small platform. The reduced cost of small platforms makes them more affordable for the limited budgets of a commercial program that need to look over the investment contention to ensure the profitability.

Now the Earth Exploration has become a business. The collected data are processed and sold making this activity profitable. Several companies act as “operators” and demand for satellites to the space manufacturer companies. The new applications demand higher data rates to send the collected data during the short time of visibility. There are few allocated frequency bands to the EES (Earth Exploration Satellite) service. S Band (2025-2110 MHz uplink, 2200-2290 MHz downlink) is shared with the SO (Space operation) and SR (Space research) services and due to the increased number of missions and proximity of terrestrial mobile communications bands, the interference levels are increasing. X band (8025-8400 MHz) allows higher data rates but only for the downlink (no uplink allocation on X band). Ka band (25500-27000 MHz) is also allocated only for downlink but at present no off the shelf hardware is available. From these facts we deduce the need of at least an S band TT&C system for the housekeeping TC/TM (and RG) and another X band system for the Payload TM. One approach is straightforward: to use the same S band system for housekeeping and payload TM. With an increased capability of the TM data rate, missions that demand for moderate TM bit rates can use a single band TT&C for both purposes with the consequent reduction on mass and consumption. If we look at the limits and regulations of the modulation formats, the classic PCM/PSK/PM modulation format (with subcarrier) is limited to 60 Ksps. The low spectral efficiency of the SP-L/PM and the same regulations limit this modulation format to 2 Msps.

1 ITU Recommendation 17-2R1
Higher data rates are forced to use suppressed carrier modulations. In practice these limits are much lower, and missions with moderate data rates need to use suppressed carrier modulations with better spectral efficiency like BPSK and QPSK (and all their variants). New on board equipment has been developed to serve both functions, housekeeping TTC and Payload TM transmission, using the new modulation formats.

The main drawback of the suppressed carrier modulations is the incompatibility with the classic tracking systems (two tones, MPTS or STDN). The tracking tones and the TM data on the downlink would occupy the same frequency band making incompatible simultaneous TM and RG. Additionally, the different modulations required for TM and RG would increase the complexity of the equipment. We need a different way to perform the positioning of the satellite. Nowadays LEO satellites are covered by the GPS and space qualified receivers are available, we can know use GPS system to determine the position of the satellite without the need of complex tracking procedures. This position can be then transmitted to the Earth Station within the housekeeping TM locating exactly the satellite.

Based on the recurring PROTEUS platform which uses ALCATEL ESPACIO compact TTC S-band transceivers, a serie of low or medium orbiting satellites dedicated to Earth Exploration or navigation services is scheduled for the next years as it follows (dates and characteristics are only given for information):

At the End of 2001, **JASON-1** will replace Topex-Poseidon. Collected data by Jason-1 make it possible to estimate the level of the oceans at any point with a 2 cm accuracy. This satellite will have an orbit with a 66° inclination at an altitude of 1336km, to ensure coverage of virtually all the ice-free oceans. The payload comprises a POSEIDON 2 radio-altimeter (13.6 and 5.3 GHz), a JMR (Jason Microwave Radiometer), a very accurate DORIS positioner using a ground stations network, a TRSR (Turbo Rogue Space Receiver) positioner using GPS constellation, and a reflector laser.

**CENA** will be the second scientific mission after JASON-1 (in 2004), and is a mission dedicated to study the impact that clouds and aerosols have on the Earth’s radiation balance. Radiation balance is the difference between energy from the sun that reaches the Earth and the energy that is lost to space. This balance controls the temperature of the Earth. This satellite will have a near sun-synchronous orbit at an altitude of about 700 km. The payload comprises 4 optical instruments (a lidar (Laser Infra-red Detection and Ranging), a visible wide-field camera, and an imaging infrared radiometer (IIR)).

**COROT** will be the third scientific mission after JASON-1 (in 2004), and is a very high accuracy stellar photometry experiment, implementing asterosismology and the search of exoplanets. For this program, very accurate stellar photometric techniques will be implemented to measure the variations in light emission received from a star over a long time period, in order to study the inner structure of the star. A second scientific purpose is the detection of planets gravitating around stars, by measuring fluctuation in the intensity of light. This satellite will have a circular orbit with a 90° inclination at an altitude of about 800-900km, to ensure coverage of virtually all the ice-free oceans. The payload comprises an afocal telescope, a dioptic lens system, a focal block, an optical baffle, service and image-processing electronic cases.

The main applications of **MEGHA-TROPIQUES mission** relate to seasonal variations in the water cycle and energy exchanges within the land-ocean-atmosphere system in tropical zones. This mission involves important issues for the economic development of countries in tropical areas, primarily with regard to agriculture and the management of water resources. Orbiting at an altitude of 800 km with a 20° inclination makes it possible to obtain up to six observations a day over the entire region. The satellite will carry on board a Madras microwave radiometer to study rainfall and cloud properties; a ScaRab radiometer for measuring top-of-the-atmosphere flux radiation, and a Saphir microwave profiler to measure atmospheric water vapour distribution.

The soil moisture and ocean salinity mission **SMOS** is an ESA’s Living Planet Programme. Its main objective is to study ocean salinity, the water cycle and soil moisture, which are all vital indicators for weather forecasting, climate monitoring and the prediction of extreme events. This satellite will have a sun-synchronous orbit at an altitude of about 600-850 km.

SMOS will use a multi-beam radiotelescope to detect 21-centimetre radiation from the land surface, the intensity of which is a good indicator of soil moisture. The same radiation coming from the ocean will reveal the salt content of the sea surface, which has a major influence on ocean currents and hence on the climate.

Regarding **MEO** (Medium Earth Orbit) application, **GALILEO**, a constellation of 24 small satellites partly based on PROTEUS functional chains will offer the first civilian space and ground navigation system with enhanced free or charged services w.r.t accuracy, availability and integrity. At very short term, a **GEM** (GALILEO Experimental Model) is proposed by ALCATEL SPACE with a compact PROTEUS TTC subsystem operating in a TM rate range of 10kbits/s to 300Kbits/s.

**ADVANTAGES OF S BAND FOR SMALL PLATFORMS**

One of the main constraints of TT&C systems is the need to work properly during all the phases of the satellite life. The most critical phases are LEOP and emergency. Many GEO satellites have two TT&C subsystems working in two
different bands; one for LEOP and emergency and the second one (allocated inside the communications band) for nominal operations.

For Earth Exploration Service, the only allocated bands are S Band and X Band. The uplink only can be allocated in S Band, and X band is mainly employed for very high data rate links. An S band communication system can provide all the communication needs of a small satellite (Housekeeping TC and TM and payload TM) for moderate payload data rates, during all the phases of the satellite life. Additionally LEO satellites are critical during emergencies due to the short visibility periods. S Band has been employed during a long time and there is a wide network of ground stations [1] making easier to follow and recover the satellite in case of trouble.

The TTC system in S band is very compact and has omni-directional coverage (useful for LEOP and emergency phases and for LEO satellites that move fast relatively to the ground station during operation. The antennae are very small and light compared with communication antennae at other bands.

MODULATION FORMATS

The uplink requirements are not very different from the requirements of other satellites. The TC data rates are low enough to be accommodated in the existing TTC standard. The uplink employs PCM/PSK/PM classic modulation with subcarriers of 8 or 16 kHz and data rates up to 4 Kbps. This modulation format is not efficient on the bandwidth usage but is very reliable because the presence of residual carrier helps to lock and track the received signal. Additionally, all the operational procedures have demonstrated to be reliable under emergencies.

The low spectral efficiency can be tolerated in the uplink because the data rate is low. However the situation is quite different when the S band downlink is used for the payload TM. The bandwidth limitations, power spectral density limits, and ITU regulations impose severe constraints on the downlink. Classic PCM/PSK/PM format is no more feasible and more efficient modulation techniques are needed.

CCSDS and ITU recommendations put limits for PCM/PSK/PM modulation than in practice give limits around 10 Ksps. The practical limit for SP-L/PM modulation is a few hundreds of Ksps. For missions demanding downlink data rates between 100 Ksps and 2 Msp, carrier suppressed modulation formats are the preferred choice. Missions demanding very high data rates (up to 200 Msp) need to implement an additional X band TM system.

BPSK and QPSK appear as the suppressed carrier modulations preferred for these applications. Pulse shaping (or spectral confinement) can be implemented for applications in which the allocated band is close to the minimum band required for the mission data rate.

There are some open points that shall be closed when implementing these new modulations. One of the problems is on the ground segment, because the ground stations shall be prepared for the different modulation format. The specification of a digital suppressed carrier transmitter/receivers shall be focused on different parameters than a linear phase modulation system. Terms as phase error, amplitude error and jitter appear in the place of modulation linearity, residual AM and phase noise. Additionally, the design of the hardware shall take into account new parameters as the technological losses, spectrum confinement and roll-off (for shaped transmitters), the non-linearity of the amplifiers (PM is not sensitive with saturated amplifiers but QPSK does) and spectral regrowth between other issues.

DESCRIPTION OF THE PROTEUS PLATFORM

The PROTEUS platform has been designed to be compatible with various orbits (phased, sun synchronous, frozen and inertial orbits) with altitudes ranging from 500 km to 1500 km, for an orbital plane inclination contained between 15 and 145deg. The platform with its folded solar arrays is compatible with small launch vehicles with fairing internal diameters above 1.9 m.

The platform provides a wide range of payload pointing capabilities (Earth and anti-Earth pointing, inertial pointing); typical pointing performance is 0.05 deg (3σ).

A satellite based on PROTEUS belongs to the 500 kg class with a payload weighing between 100 kg to 300 kg, consuming up to 300 W power.

Table 1 summarizes the main characteristics and related performances of the PROTEUS platform.

<table>
<thead>
<tr>
<th>Orbit</th>
<th>any orbit altitude in 500-1500 km; orbit inclination higher than 15 deg.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Launch vehicles</td>
<td>compatible with all launch vehicle with fairing diameter &gt; 1.9 m</td>
</tr>
<tr>
<td>Mass</td>
<td>bus dry maximum mass = 270 kg; 28 kg hydrazine capacity</td>
</tr>
<tr>
<td></td>
<td>Payload mass = 100 to 300 kg</td>
</tr>
<tr>
<td>Reliability</td>
<td>0.875 over 3 years; 0.749 over 5 years</td>
</tr>
<tr>
<td>Lifetime</td>
<td>3 to 5 years depending on the orbit</td>
</tr>
<tr>
<td>Pointing</td>
<td>0.05 deg (3σ) on each axis</td>
</tr>
<tr>
<td>(improved when attitude loop closed on instrument)</td>
<td></td>
</tr>
<tr>
<td>Power</td>
<td>bus maximum consumption = 300 W; Payload consumption class = 200 W</td>
</tr>
<tr>
<td></td>
<td>Payload consumption class = 200 W up to 300 W on some orbits</td>
</tr>
</tbody>
</table>
Table 1: PROTEUS main characteristics

<table>
<thead>
<tr>
<th>Data storage</th>
<th>2 Gbits for payload</th>
</tr>
</thead>
<tbody>
<tr>
<td>Down link rate</td>
<td>839 kbits/s routine phase; 10 kbits/s transfer and emergency phases</td>
</tr>
<tr>
<td>Up link rate</td>
<td>4 kbits/s</td>
</tr>
<tr>
<td>Unavailability</td>
<td>0.88 %</td>
</tr>
</tbody>
</table>

Figure 1 shows the general lay-out of a PROTEUS platform. PROTEUS TTC subsystem is well identified thanks to the Figure 1 arrow on the Y panel of the PROTEUS platform and the Figure 2 below allows a focusing on it.

The PROTEUS TTC subsystem is comprised by the following elements:

1. **TTC transceivers:** Both transceivers fill up an envelop volume of around 284*220*197mm³ and have a mass of around 6.18Kg. Each transceiver includes a diplexer, a receiver and a transmitter. The two receivers work in hot redundancy (no TC ON/OFF are available) while the transmitters work in cold redundancy (each transmitter can be turned ON or OFF via a TC sent by Ground).

The block diagram of the equipment is shown in Figure 4:

The Diplexer allows to operate simultaneously the Receiver and the Transmitter with just a single RF antenna input/output port. The Diplexer also isolates Transmitter and Receiver and helps to filter the spurious of the SSPA.

The receiver assures the reception of signal in the range of 2025-2120 MHz. Its main function is to demodulate the RF signal with a 16kHz subcarrier from PM/BPSK to NRZ-L which is then sent to Packet Telecommand Decoder (PTD) located inside the Data Handling Unit (DHU). The receiver lock threshold is \( \approx -129\text{dBm} \) while the demodulation threshold has been restricted to \(-119\text{dBm}\). No correcting code is used for the uplink transmission which is specified for a BER of \( 10^{-5} \).
The transmitter section generates a carrier in the 2.2-2.3 GHz band. This carrier is locked to an internal reference (quartz crystal). It also performs the QPSK modulation of the carrier with the modulating signal coming from the DHU. The Power FET's based SSPA amplifies this signal up to the required output power. Then, an output filter reduces the harmonics generated by the SSPA, a directional coupler with one detector allows to measure the output power, and an output isolator assures the output impedance and protects the output transistor from accidental short circuits. The transmitter inputs receive the I and Q data already Reed Solomon (RS) and Convolution (CV) encoded from the DHU to be directly QPSK modulated. It can be noticed that due to the produced orthogonal spectrums, the band pass is divided by a factor 2 at constant data rate in comparison with a BPSK scheme modulation. The transmitter realizes the digital data with the clock and conforms two balanced inputs for the modulator. A previous premodulation filtering is made before modulating. The objective is to meet the RF masks for spurious and modulation products. This filter has been optimized to the maximum bit rate required for the application (up to 2000 kbits/s). The modulation is performed directly at the output carrier frequency. The mapping onto the QPSK constellation is made according to Gray encoding. The residual amplitude modulation (RAM) and the phase accuracy can be adjusted and reduced to 0 at the beginning of life and at ambient temperature. However some degradation typically no more than 0.5 dB and $\pm 3^\circ$ happens due to the temperature and aging effects.

**Figure 5** Measured QPSK constellation

Figure 5 shows a typical QPSK constellation produced by the PROTEUS transmitter and demodulated by an ideal receiver. The RF carrier frequency is 2.215 GHz and the symbol rate is 2290MHz is $\approx 38.3$ dBm while the applied one to each antenna becomes $\approx 34.2$ dBm due to power divider and coaxial cables losses.

The technological loss of the PROTEUS transmitter is calculated by using the average Error Vector Magnitude (EVM), which gives a value of 0.1 dB for a BER of $10^{-5}$. Since pulse shaping is not used, the transmitter output power amplifier can operate in saturation without increasing significantly the technological loss.

2. **3dB SMA connectorised hybrid coupler:**
   This four ports coaxial coupler weighting around 36g fills up an envelop volume of around 32*38*13mm and it is called a large band power divider able to work in a frequency range of 0.1-18GHz. On one hand, it allows the coupling from both TTC antennas to both transceivers for what concerns the TC uplink. On the other hand, it ensures either the coupling from main or redundant transceiver for what concerns the TM downlink. By this way, it has to be noticed that no RF switch has been implemented increasing as a consequence the TTC subsystem reliability figure. Moreover, the Earth (+Z) and the anti-Earth (-Z) TTC antennas are always operating together.

3. **Low loss coaxial cables**
   Coaxial cables used are SHF5 type SMA connectorised with maximum lengths of 600mm between transceivers and power divider input ports and 2000mm between power divider output ports and S-band antennas input ports. The RF harness mass does not exceed 323g. In the S-band from 2025 to 2290 MHz, the RF losses to be taken into account are $\approx 1.1$dB either for Earth or anti-Earth antenna paths.

4. **Antenna spacer masts**
   Such antenna spacers of 273 mm length have been designed to avoid any RF interference with folded solar arrays during Low Earth Orbit Positioning (LEOP) operation.

5. **Broadband hemispherical coverage antennas**
   Hemispherical coverage antennas have a conical radome of 200mm length with a smallest $\varnothing$ of 39mm and a total mass of around 530g. They allow to ensure the requested omnidirectional coverage for transfer and satellite positioning as...
well as routine and emergency operations for nadir angles from 0° to ±85°. To avoid interference plane, opposite circular polarization is used for each antenna. (+Z) antenna is Left Hand Polarized (LHCP) while the other (-Z) antenna is Right Hand Circular Polarized (RHCP).

DESCRIPTION OF THE LEOSTAR PLATFORM
The LEOSTAR platform is basically a hexagonal box of less than 1-meter side. Up to now, the missions for those small LEOSTAR satellites (less than 500 kg) have always been earth observation with LEO trajectory. Following figures show an example of LEOSTAR application with a scientific application (ISUAL) and a remote sensing instrument (RSI) for earth observation:

![Figure 8 3D view of LEOSTAR platform](image)

The architecture of the satellite is described in Figure 9:

![Figure 9 LEOSTAR satellite architecture](image)
The TT&C RF communication function is gathering two hemispherical antennas in opposite polarisation, a 3dB-hybrid coupler and two S-band transponders. The TTC system is shown in Figure 10:

![Figure 10 LEOSTAR TT&C subsystem](image1)

![Figure 11 LEOSTAR S-Band Transponder front view](image2)

The telecommand up-link takes benefit of CCSDS standard functionality and in particular the automatic return and the authentication.

The receiver acquires the telecommand signal transmitted by the antennas via the 3dB hybrid coupler and performs a phase demodulation and a BPSK demodulation to give the data on line with a rate of 4000 bps to the handling unit. The telecommand data are in accordance with the CCSDS standard with automatic return in case of link failure and automatic authentication of the commands. The two receivers (one on each transponder) are in hot redundancy and cannot be switch off by telecommand.

The TM data are permanently transmitted in survival mode in order to guarantee the ground station lock of the satellite. Those data are in CCSDS standard. Due to the short time visibility and the high data rate that is needed (1.6 Mbps), the downlink data are BPSK (or sometimes QPSK) modulated in order to meet the ITU flux limitation requirement.

Transponders do not need the ranging function because the GPS receiver provides the position and velocity of the spacecraft in the Earth Reference Frame.

The LEOSTAR transponder three main sections are the same as for Proteus: Diplexer, Transmitter and Receiver. The Diplexer and the receiver have no significant differences with those described before, except for the reference signal that is driven from the receiver to the transmitter in coherent mode.

The frequency plan is different from the one used in PROTEUS due to the required receiver/transmitter frequency ratio (221/240) which assures the coherency between them.

The block diagram of LEOSTAR is shown in Figure 12:

![Figure 12 Block Diagram of LEOSTAR Transponder](image3)
The transmitter module generates a carrier around 2.2 GHz. A VCO is phased locked onto an internal quartz crystal (non coherent mode) or to an external reference taken from the Receiver (coherent mode). A frequency multiplication followed by a filtering conform the final 2.2 GHz carrier. This signal is filtered to eliminate 1st, 2nd, 4th and superior harmonics of the VCO signal.

The transmitter performs the BPSK modulation (or QPSK in some cases) of the 2.2 GHz carrier with the baseband TM data. An amplifier stage amplifies this signal up to the required output power. A later output filter is implemented to reduce the harmonics generated by the final amplifier.

The first equipment manufactured for LEOSTAR uses BPSK modulation. The measured BPSK constellation for LEOSTAR development is shown in Figure 13. From that table above we can extract a phase imbalance of less than 2º, and calculate the residual amplitude modulation calculated, which is less than 0.5 dB.

In this case, the technological losses calculated from the EVM value are less than 0.1 dB for a BER of $10^{-6}$.

**CONCLUSIONS**

Small satellites are an emerging market with many applications for the Earth Exploration Service. The need of small and light TTC systems able to handle increased data rates forces the development of new solutions that include new modulation formats with suppressed carrier in order to handle housekeeping and payload TM with the same equipment.

The main differences between these systems, the new constraints they have and two practical European multipurpose implementations (PROTEUS and LEOSTAR) have been described to give an insight of the TTC systems for small satellites.

**REFERENCES**

COMPACT TT&C EQUIPMENT FOR SMALL SATELLITES

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- INTRODUCTION
- NEW DEMANDS OF TT&C FOR SMALL PLATFORMS
- ADVANTAGES OF S-BAND FOR SMALL PLATFORMS
- TWO EXAMPLES OF S-BAND TTC SUBSYSTEMS
  - PROTEUS PLATFORM
  - LEOSTAR PLATFORM
- CONCLUSIONS
INTRODUCTION

Increased number of missions
Earth Exploration has commercial applications

INCREASED IMPORTANCE OF SMALL SATELLITES

Limited budgets
Simplified requirements

NEW DEMANDS OF TT&C FOR SMALL PLATFORMS

- Requirements of TT&C subsystem for small satellites:
  - Reduced mass, volume and power budgets → Compact equipments
  - Higher data rates
  - Efficient use of the spectrum
  - Work properly all the phases of the S/L life → S-Band coverage
  - Allocated EES bands: S-Band / X-Band / Ka-Band
ADVANTAGES OF S-BAND FOR SMALL PLATFORMS

WHY USE S-BAND......?

- S-Band system can provide simultaneously Housekeeping TC&TM and Payload TM
- There is a wide network of ground stations making easier to follow and recover the satellite in case of trouble
- Compact system with omnidirectional coverage.
- Antennae are small and light
- The only allocated band for uplink EES TT&C is S-Band

S BAND MODULATION PARAMETERS

Uplink:
- TC data rates are low
- PCM/PSK/PM classic modulation
- 8 or 16 kHz subcarries
- Data rates up to 4 kbps
- Format very reliable due to the residual carrier which helps to lock and track the received signal

Downlink:
- Classic formats (PCM/PSK/PM or SP-L/PM) not feasible for high data rates required.
- Suppressed carrier techniques are preferred for rates between 100 Kbps and 2 Mbps: BPSK, QPSK
- Pulse shaping or spectral confinement can be implemented
- Ground stations shall be prepared for these new formats.
DESCRIPTION OF PROTEUS PLATFORM

MAIN CHARACTERISTICS OF PROTEUS PLATFORM

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>Orbit</td>
<td>any orbit altitude in 500-1500 km; orbit inclination higher than 15 deg.</td>
</tr>
<tr>
<td>Launch vehicles</td>
<td>compatible with all launch vehicle with fairing diameter &gt;1.9 m</td>
</tr>
<tr>
<td>Mass</td>
<td>500 kg class</td>
</tr>
<tr>
<td></td>
<td>Payload mass = 100 to 300 kg</td>
</tr>
<tr>
<td>Lifetime</td>
<td>3 to 5 years depending on the orbit</td>
</tr>
<tr>
<td>Power</td>
<td>bus maximum consumption = 300 W</td>
</tr>
<tr>
<td>Data storage</td>
<td>2 Gbits for payload</td>
</tr>
<tr>
<td>Down link rate</td>
<td>839 kbits/s routine phase; 10 kbits/s transfer and emergency phases</td>
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<td>Missions</td>
<td>JASON: estimate the level of the oceans</td>
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<td>CENA: study the impact of clouds and aerosols on Earth’s radiation balance</td>
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<tr>
<td></td>
<td>COROT: very high accuracy stellar photometry experiment</td>
</tr>
<tr>
<td></td>
<td>MEGA-TROPHIQUES: climatic studies in tropical zones</td>
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</table>

3dB SMA connectorised hybrid coupler
TTC Transceivers
Low loss coaxial cables
Antenna spacer masts
Broadband hemispherical coverage antennae
DESCRIPTION OF PROTEUS PLATFORM

PROTEUS S Band Transceiver

Block Diagram of PROTEUS Transceiver

PROTEUS S Band Transceiver

Measured QPSK constellation

PROTEUS performances

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
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<tbody>
<tr>
<td>Receiver threshold</td>
<td>-128 dBm</td>
</tr>
<tr>
<td>Demodulation threshold @ 10^-5 BER</td>
<td>-119 dBm</td>
</tr>
<tr>
<td>Output power at diplexer</td>
<td>38.3 dBm</td>
</tr>
<tr>
<td>Uplink modulation</td>
<td>PCM/BPSK/PM</td>
</tr>
<tr>
<td>Downlink modulation</td>
<td>QPSK</td>
</tr>
<tr>
<td>Phase Error</td>
<td>+3º</td>
</tr>
<tr>
<td>Amplitude Error</td>
<td>&lt; 0.5 dB</td>
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DESCRIPTION OF LEOSTAR PLATFORM

Main characteristics of LEOSTAR platform

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<th>Characteristic</th>
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<tr>
<td>Orbit</td>
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</tr>
<tr>
<td>Mass</td>
<td>100-500 kg class</td>
</tr>
<tr>
<td>Payload mass</td>
<td>400 to 800 kg (Leostar 500)</td>
</tr>
<tr>
<td></td>
<td>200 to 400 kg (Leostar 200)</td>
</tr>
<tr>
<td>Lifetime</td>
<td>Up to 5 years</td>
</tr>
<tr>
<td>Payload available</td>
<td></td>
</tr>
<tr>
<td>Power</td>
<td>Typical 450 W (up to 1000 W) (Leostar 500)</td>
</tr>
<tr>
<td></td>
<td>Typical 250 W (up to 600 W) (Leostar 200)</td>
</tr>
<tr>
<td>Down link rate</td>
<td>1600 Kbps</td>
</tr>
<tr>
<td>Up link rate</td>
<td>4 kbit/s</td>
</tr>
<tr>
<td>Missions</td>
<td>Earth observation, science, telecoms</td>
</tr>
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</table>

LEOSTAR TT&C subsystem

LEOSTAR S-Band Transponder front view
DESCRIPTION OF LEO STAR PLATFORM

Multiplier /N
/X'T al
QPSK MOD
/M
Multiplier ADC
PM
DEM O
DAC
BPSK DEM O
ASIC
TC
/X' Tal
Fref

Diplexer
RF Conector
TM Data
Receiver threshold -128 dBm
Demodulation threshold @ 10^-5 BER -119 dBm
Output power at diplexer 37 dBm
Uplink modulation PCM/BPSK/PM
Downlink modulation BPSK
Phase Error + 3º
Amplitude Error < 0,5 dB
Turnaround ratio Ftx/Rrx 240/221

LEOSTAR performances
Receiver threshold -128 dBm
Demodulation threshold @ 10^-5 BER -119 dBm
Output power at diplexer 37 dBm
Uplink modulation PCM/BPSK/PM
Downlink modulation BPSK
Phase Error + 3º
Amplitude Error < 0,5 dB
Turnaround ratio Ftx/Rrx 240/221

Measured LEO STAR BPSK constellation

Measured B.E.R of LEO STAR (RX-EQM)
CONCLUSIONS

- Small satellites are an emerging market with many profitable applications for the EES (Earth Exploration Service)
- Market trends impose reduction on budgets and costs
- S-Band TT&C subsystem shall handle with high data rates and new modulation formats.
- Small and light TT&C systems as PROTEUS and LEO STAR are able to perform housekeeping and payload TM with the same equipment.